Europ. J. Agronomy 34 (2011) 190–195

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Nitrogen partitioning and utilization in corn cropping systems: Rotation, N source, and N timing

Guillermo Hernandez-Ramirez[a,*], Sylvie M. Brouder[b], Douglas R. Smith[c], George E. Van Scoyoc[b]

[a] New Zealand Institute for Plant and Food Research, Canterbury Agriculture and Science Centre, Private Bag 4704, Christchurch, New Zealand
[b] Agronomy Department, Purdue University, West Lafayette, IN 47907-2054, United States
[c] USDA-ARS, National Soil Erosion Research Laboratory, West Lafayette, IN 47907-2054, United States

ARTICLE INFO

Article history:
Received 15 March 2010
Received in revised form
23 December 2010
Accepted 29 December 2010

Keywords:
N partitioning
N utilization
Harvest index
Crop rotation
Swine manure

ABSTRACT

Nitrogen partitioning and utilization can partly control plant productivity. This study was conducted to estimate dry matter (DM) and N partitioning parameters in corn (*Zea mays* L.) as affected by N source, N timing, and crop rotation. We quantified yield by combine, aboveground DM accumulation [residues (stalk + cob) and grain], and C and N concentrations at growth stage R6 of corn continuously cropped (CC) or in rotation with soybean [*Glycine max* (L.) Merr.] (CS) and fertilized with side-dressed urea-ammonium nitrate (UAN) or with liquid swine manure applied in either spring (SM) or fall (FM). Of the assessed N partitioning parameters, N utilization showed the highest association with yield ($r = 0.94^{***}$). Across treatment means, 72% of these increases in N utilization could be attributed to increases in N uptake. On the contrary, N harvest index (NHI) exhibited nearly constant values across experimental units, and therefore, NHI showed a minor relative contribution to variations in N utilization, thus supporting the basic premise of low NHI dependency on environment or management. Both N uptake and N utilization were driven by type of N addition (UAN > manure). Also, corn N utilization and yield were greater (10–13%) within the corn–soybean rotation, suggesting that a shift in land use from crop rotations into more continuous corn due to increasing demand for corn grain may impose additional challenges for enhancing plant N nutrition and sustaining yield.

1. Introduction

Achieving and sustaining optimum yield is a continuous challenge in agricultural systems. To meet these crop productivity goals is nowadays becoming even more complex due to the increasing interest in using plant residues for biofuel production and its potential repercussions on nutrient cycling and partitioning. One approach for pursuing an overall, superior efficiency of production systems is by developing and effectively using an enhanced understanding of plant partitioning processes (e.g., DM and nutrient allocation into grain) (Rajcan and Tollenaar, 1999; Kumudini et al., 2001; Worku et al., 2007; Dordas, 2009).

Work by Worku et al. (2007) in N-limited soils supports N utilization as a key driver of crop response and efficiency. However, current knowledge is limited with respect to the underlying mechanisms controlling plant partitioning including N utilization. As suggested by Rajcan and Tollenaar (1999) and Kumudini et al. (2001), controls on plant N partitioning process may be revealed by examining the relative contribution of N uptake and NHI to N utilization. Nonetheless, the majority of the existing reports concerning N partitioning focus mostly on genetic improvement employing one-single N management (Kumudini et al., 2001; Worku et al., 2007). Indeed, to date few studies (Loecke et al., 2004; Kwaw-Mensah and Al-Kaisi, 2006; Dordas, 2009) have focused on the impacts of diverse N management on plant partitioning parameters such as HI and/or NHI. Moreover, none of these existing reports have assessed the comparative effects of various crop rotations, N sources, and manure timings on corn N partitioning parameters. Thus, the objective of this study was to assess the effects of crop rotation, N source, and N timing on N partitioning parameters and associated yield response in corn cropping systems.

2. Materials and methods

2.1. Site and treatment descriptions

This study was conducted at the Purdue University Agronomy Center for Research and Education, West Lafayette, Indiana (lat 40° 29′ 55.20″ N and long 86° 59′ 53.23″ W, 215 m elevation). The soil series are Drummer silty clay loam (fine-silty, mixed, superactive, mesic Typic Endoaquoll) and Raub silt loam (fine-silty, mixed,

* Corresponding author. Tel.: +64 3 325 9637; fax: +64 3 325 2074.
E-mail address: Guillermo.Hernandez@plantandfood.co.nz (G. Hernandez-Ramirez).

1161-0301/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.eja.2010.12.002

superactive, mesic Aquic Argiudoll). The mean air temperature and annual precipitation at the site are 12 °C and 950 mm, respectively (data from 1977 to 2006).

This experiment was arranged in a randomized complete block design with four replicates. Plots were 10 m wide and 48.5 m long. Plots were drained with plastic tile lines installed at a depth of 0.9 m with a spacing of 10 m. The treatments included a corn–soybean rotation with sets of experimental plots for both crops (corn: CS and soybean: SC) in any given year, and continuous corn (CCs). The N sources for corn were urea-ammonium nitrate 28% N (UAN) side-dressed at corn growth stage V5 at rates of 157 kg N ha^{-1} yr^{-1} for CC and 135 kg N ha^{-1} yr^{-1} for CS, and liquid swine manure (C/N ratio: 2:1, 80% of N as NH_4^+) injected into CC at a rate of 255 ± 24 kg N ha^{-1} yr^{-1} in either the spring [spring manure (SM)] or the fall [fall manure (FM)]. The five treatments were CCSM, CCFM, CCUAN, CSUAN, and SC. Both UAN and manure were placed at a depth of 0.10 m in the soil by mechanic knife and injector, respectively.

Tillage operations were chisel in the fall and chisel plus disk in the spring for all cropped plots, except that SC and CCFM experimental plots did not receive fall chisel tillage. Corn (*Z. mays*) hybrid B5737CL and soybean (*G. max*) B323 were typically planted in early May at a population density of 73 142 and 469 490 seeds ha^{-1}, respectively. Survival rate of corn plants at maturity was 87 ± 1% in this study. Typical dates for corn R1 growth stage were on 25 July 2005 and 27 July 2006, for soybean R1 growth stage were at 17 July 2005 and 12 July 2006; and soybean R5 growth stage were 16 Sep. 2005 and 2 Sep. 2006. Soils were tested each fall for general fertility using recommended protocols, and results indicated soil P, K, and pH were non-limiting. Further information about the experiment management can be found in Hernandez-Ramirez et al. (2009a,b).

2.2. Plant samples collection, partitioning, and analyses

Corn yield was monitored from 1999 to 2006 in the four middle rows (i.e., 3 m wide) of each experimental plot using a plot combine with weighing wagon. Corn stalks (n = 10 plants per plot) were regularly collected at plant maturity during these experimental years. Additionally, aboveground plant materials (i.e., 16 plants per plot) were also collected in the years 2005 and 2006 to assess DM and N accumulation and partitioning at plant maturity. As Liu et al. (2004), entire corn plants from random positions within the four middle rows in each experimental plot were cut by hand at the soil surface level at growth stage R6 on 11 Oct. 2005 and 26 Sep. 2006. The sampling area was bordered by four rows on each side and at least 2 m border area within the rows at each end of every experimental plot. Samples were handled to avoid any contamination with soil particles. Samples were dried for 72 h at 60 °C in a forced air oven; weights were recorded before and after drying to estimate DM. Dried plants were separated into stalks (including tassel, leaves, and husk) and ears (grain and cob), and subsequently, ears were hand shelled to separate grain from the cobs.

Aboveground DM and population count in SC were also determined at the R5 growth stages on 16 Sep. 2005 and 2 Sep. 2006 from three random positions (0.38 m^2) within each plot. Grain yield by combine was also quantified in SC.

Plant materials were ground in a UDY mill (UDY Corp., Ft. Collins, CO) to pass through a 0.5 mm screen, stored at room temperature, and subsequently analyzed by dry combustion using approximately 0.07 g of plant material and employing a Leco CHN 2000 (Leco Corp., St. Joseph, MI) equipped with infrared cell and thermal conductivity detectors for C and N concentrations, respectively.

2.3. Data analyses

Masses of plant materials were expressed on DM basis. Corn grain harvested by combine was adjusted to a water content of 155 g kg^{-1}. Masses of stalk and cob parts were added, and these values were reported as aboveground corn residue. Subsequently, C and N content data were used to calculate N masses and C/N ratios in each plant part. Two different harvest indexes (HI; dimensionless) were calculated to estimate aboveground partitioning for both DM and N as follows:

$$\mathrm{DMHI} = \frac{G_{\mathrm{DM}}}{AB_{\mathrm{DM}}} \quad (1)$$

$$\mathrm{NHI} = \frac{G_{\mathrm{N}}}{AB_{\mathrm{N}}} \quad (2)$$

where G is grain and AB is total aboveground biomass.

We separated the relative contribution of both aboveground N partitioning (NHI) and aboveground plant N uptake (Nuptake) to N utilization after Kumudini et al. (2001). Fractional aboveground NHI contribution (fNHI) can be expressed as follows:

$$\mathrm{fNHI} = \frac{\ln[100 \times (\mathrm{NHI}_1 - \mathrm{NHI}_0)/\mathrm{NHI}_0]}{\ln[100 \times (\mathrm{Nuptake}_1 - \mathrm{Nuptake}_0)/\mathrm{Nuptake}_0] + \ln[100 \times (\mathrm{NHI}_1 - \mathrm{NHI}_0)/\mathrm{NHI}_0]} \quad (3)$$

where the subscripts 0 and 1 indicates incremental change for each variable at lower and higher values, respectively. Fractional aboveground plant N uptake contribution (fNuptake) was directly calculated as follows:

$$\mathrm{fNuptake} = 1 - \mathrm{fNHI} \quad (4)$$

We examined the relationships among variables by Pearson Product Moment Correlations (r). Treatment effects were assessed by analysis of variance (ANOVA) models (PROC GLM) followed by Tukey Honest Significant Distance (HSD) and pre-selected contrasts tests for multiple treatment mean comparison. Statistical analyses were performed using SAS 9.1 (SAS Institute, 2002) at a critical level of 0.05.

3. Results

3.1. Corn DM, N accumulations, and HIs

On the basis of 4-yr means (1999–2002), we found significant treatment differences in corn yield, N mass accumulated in grain, and N concentration in stalks (Table 1). Manure treatments (CCFM and/or CCSM) typically exhibited inferior performance than CSUAN. These patterns became more evident in the later years of the experiment [i.e., 2001, 2002 (Table 1); 2005, 2006 (Table 2)] perhaps suggesting incremental carry over effects with time. For example, yield and grain mass were 7–15% lower for CCFM than for the average of the other treatments based on the 2-yr means (Table 2).

Total aboveground N uptake (N grain + residue N accumulation) was significantly higher in treatments receiving UAN than in manured treatments (Table 2). Likewise, N utilization was 11% higher in the corn phase of the corn–soybean rotation (CSUAN) than in continuous corn (P = 0.024) as well as 12% higher in treatments receiving UAN vs. manure as N source (P = 0.003) based on contrast tests. In addition, we observed strong Pearson correlations between DM grain and both N utilization (r = 0.94, P < 0.001; Fig. 1A) and N uptake (r = 0.92, P < 0.001; Fig. 1B).

Table 1
Corn yield, total N concentration and N mass exported in harvested grain, and total N concentration in stalk (growth stage R6) for four experimental years.

Treatment or statistic	Experimental year				4-yr mean
	1999	2000	2001	2002	
	Yield[a] Mg ha^{-1} yr^{-1}				
CCSM	7.23	6.68	7.37 b[b]	8.44 b	7.43 b
CCFM	7.95	7.67	6.94 b	8.01 b	7.64 b
CCUAN	7.39	7.62	8.72 ab	9.01 b	8.19 ab
CSUAN	8.66	7.86	9.58 a	10.26 a	9.09 a
Mean	8.03	7.74	9.15	9.64	8.64
CV, %[c]	17.1	12.1	14.9	10.4	10.2
P > *F*[¶]	NS	NS	<0.001	<0.001	<0.001
	Grain N content g N kg^{-1} DM				
CCSM	13.4	13.1	12.6	14.5	13.4
CCFM	14.1	12.9	12.1	12.5	12.9
CCUAN	12.2	13.6	13.6	14.1	13.3
CSUAN	13.4	13.1	12.8	14.2	13.4
Mean	12.8	13.3	13.2	14.1	13.4
CV, %[c]	7.3	3.4	5.7	9.2	3.4
P > *F*[¶]	NS	NS	NS	NS	NS
	N mass in grain kg N ha^{-1} yr^{-1}				
CCSM	81.7	73.9	78.1 b	103.2 ab	84.2 b
CCFM	90.9	83.9	71.2 b	85.2 b	82.8 b
CCUAN	75.7	87.3	100.4 a	107.2 ab	92.6 ab
CSUAN	108.7	87.2	103.2 a	123.2 a	105.6 a
Mean	92.2	87.3	101.8	115.2	99.1
CV, %[c]	13.6	13.2	17.4	15.5	11.8
P > *F*[¶]	NS	NS	<0.001	<0.001	<0.001
	Stalk N content g N kg^{-1} DM				
CCSM	10.7	9.2	7.7 ab	7.6 a	8.8
CCFM	9.9	9.2	6.9 b	5.9 b	8.0
CCUAN	9.4	10.5	9.1 a	7.2 a	9.0
CSUAN	9.9	8.8	8.8 ab	8.0 a	8.5
Mean	9.0	10.0	8.5	7.5	8.8
CV, %[c]	11.2	7.9	10.7	11.3	5.6
P > *F*[¶]	NS	NS	<0.001	<0.001	NS

¶ *P* > *F*, probabilities beyond *F* values for treatment effects after ANOVA models.
a Grain harvested by self-propelled combine and adjusted to water content of 155 g kg^{-1}.
b Within columns, means followed by the same letter are not significantly different according to Tukey HSD test (α = 0.05).
c CV, coefficient of variation.

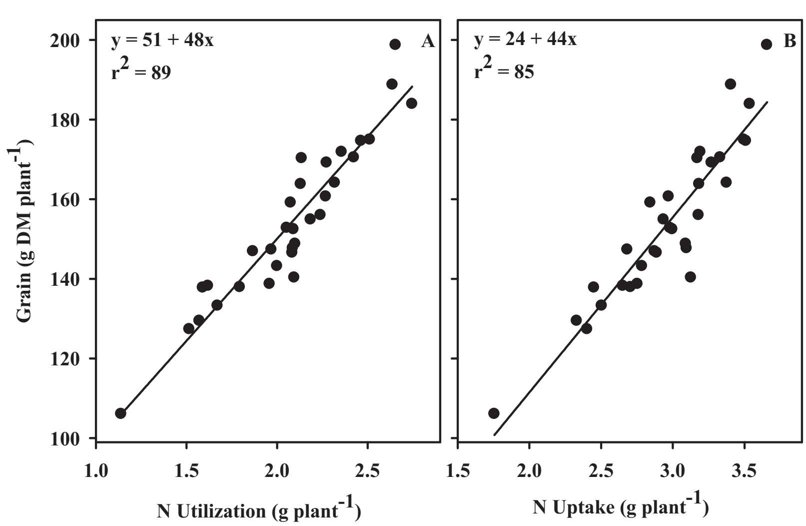

Fig. 1. Corn grain harvested by hand at growth stage R6 as a function of aboveground (A) N utilization and (B) N uptake. Each point is an experimental unit.

A contrast test found that corn DMHI values were statistically higher for UAN vs. manure treatments (CCUAN and CSUAN vs. CCSM and CCFM; *P* = 0.016; Table 2). Although not statistically significant, NHI trended higher in the corn phase of corn–soybean rotation (CSUAN) than in all other corn treatments (CCSM, CCFM and CCUAN) (Table 2). As expected, NHI increased as both grain N content and DM grain increased (Fig. 2) with Pearson correlations of 0.67 and 0.65, respectively (*P*s < 0.001).

Table 2
Corn yield and aboveground dry matter (DM) and nitrogen accumulation and partitioning (harvest index, HI) at growth stage R6 using liquid swine manure (M) or urea-ammonium nitrate (UAN) as N source in corn cropped continuously (CC) or in rotation with soybean (CS). Each 2-yr treatment mean averaged 8 experimental units.

Treatment or statistic	Yield[a]	DM accumulation		DMHI	N accumulation		N Uptake	NHI[b]	C/N ratio	
		Grain	Residue		Grain	Residue			Grain	Residue
	Mg ha^{-1} yr^{-1}				kg ha^{-1} yr^{-1}					
	2005									
CCSM	9.9	9.2 b[c]	9.3	0.49 b	107 b	60	167 b	0.64	38 a	70
CCFM	9.1	10.5 ab	9.7	0.52 ab	144 a	63	207 ab	0.70	33 b	69
CCUAN	9.8	10.8 a	8.8	0.55 a	146 a	62	208 ab	0.70	33 b	64
CSUAN	10.4	10.7 a	9.2	0.54 a	153 a	65	218 a	0.70	31 b	64
Mean	9.8	10.3	9.3	0.53	137	63	200	0.68	34	67
P > *F*[¶]	NS	**	NS	**	**	NS	*	NS	*	NS
	2006									
CCSM	10.4 bc	13.2 a	10.7	0.55	183 a	66	250 a	0.73	32	70
CCFM	8.9 d	10.8 b	10.3	0.51	140 b	66	206 b	0.68	35	68
CCUAN	10.9 ab	12.4 a	10.9	0.53	171 a	74	245 a	0.70	33	63
CSUAN	11.7 a	12.6 a	10.0	0.56	175 a	64	239 a	0.73	32	69
Mean	10.5	12.3	10.5	0.54	167	68	235	0.71	33	68
P > *F*[¶]	***	**	NS	NS	**	NS	*	NS	NS	NS
	2-yr mean									
CCSM	10.1 a	11.2 a	10.0	0.53	145 bc	63	208	0.70	34	68
CCFM	9.0 b	10.7 b	10.0	0.52	142 c	65	207	0.69	34	68
CCUAN	10.3 a	11.6 a	9.9	0.54	158 ab	68	226	0.70	33	63
CSUAN	11.1 a	11.7 a	9.6	0.55	164 a	65	229	0.72	32	65
Mean	10.1	11.3	9.9	0.53	152	65	217	0.70	33	66
CV, %	5	4	5	3	5	11	6	3	4	12
P > *F*[¶]	**	**	NS	NS	**	NS	NS	NS	NS	NS
Contrast										
UAN vs. M[d]	*	**	NS	*	**	NS	**	NS	NS	NS
CC vs. CS	*	NS	NS	NS	*	NS	NS	NS	NS	NS

*,**,*** Significant at 0.05, 0.01, and 0.001 probability levels, respectively.
¶ $P > F$, probabilities beyond F values for treatment effects after ANOVA models.
a Grain harvested by self-propelled combine and adjusted to water content of 155 g kg^{-1}. All other variables were measured after sample collection by hand at growth stage R6.
b Aboveground N partitioning calculated as N harvest index [NHI = Ngrain/(Ngrain + Nresidue)]
c Within columns, means followed by the same letter are not significantly different according to Tukey HSD test (α = 0.05).
d M encompasses continuous corn under spring (CCSM) and fall (CCFM) liquid swine manure applications.

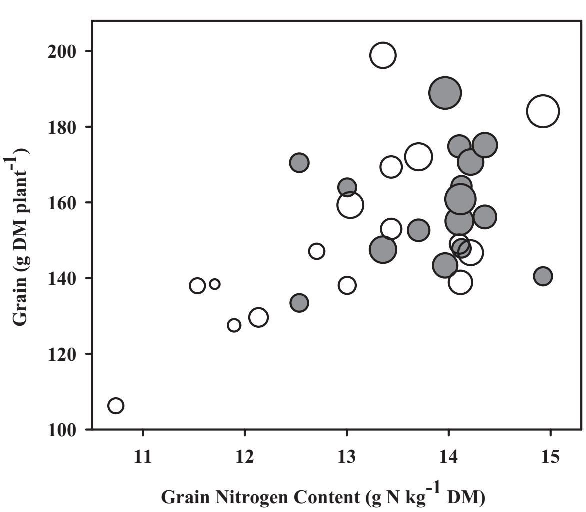

Fig. 2. Aboveground nitrogen partitioning (NHI) as a function of dry matter (DM) accumulation and N content in corn grain at growth stage R6. The area of the circles corresponds to NHI values ranging from 0.61 to 0.79. Open and closed circles correspond to experimental plots receiving manure and UAN as N source, respectively.

3.2. N contents and C/N ratios

For the 2005 and 2006 data, grain N concentration was 7% higher in CSUAN than in the average of the three continuous corn treatments (CCUAN, CCSM and CCFM) with 14.1 and 13.2 g N kg^{-1} DM grain, respectively (P = 0.037, data not shown). Grain N concentration significantly correlated to DM grain on the basis of this 2-yr data (r = 0.56, P = 0.001). Although not statistically significant, N concentrations in aboveground residue trended toward higher values in CSUAN than in the average of our three CC treatments (CCUAN, CCSM and CCFM) with 7.2 and 6.8 g N kg^{-1} DM, respectively.

Within the corn residue fraction, we evaluated cobs separately from the rest of residue parts (i.e., stalk, leaves, tassel, and husk). Corn cobs were a near constant mass fraction of the entire aboveground plant. Nine percent of aboveground plant DM and 5% of aboveground plant N were allocated in the cobs. Corn cob registered a C/N ratio of 91 ± 6, while the rest of residue was 64 ± 2 (data not shown).

As anticipated, C/N ratios in both SC canopy at growth stage R5 and SC grain at harvest were narrow (15.9 ± 0.4 and 7.8 ± 0.1, respectively); N contents in these two SC materials were 28.6 ± 0.8 and 65.1 ± 0.7 g N kg^{-1} DM, respectively. Aboveground DM in SC at growth stage R5 averaged 11140 ± 620 kg DM ha^{-1} yr^{-1} with a plant population count of 405 100 ± 16 200 plant ha^{-1}, while SC grain mass at harvest was 2890 ± 85 kg DM ha^{-1} yr^{-1}.

4. Discussion

4.1. Distinguishing NHI and N uptake contributions to corn N utilization

Of the partitioning parameters assessed, N utilization showed the highest association with corn yield in this study. Correlation analyses by Worku et al. (2007) in corn fields in Eastern Africa also support the driving-role of N utilization on grain yield performance, particularly under low N fertilizer additions. Increasing N utilization values may be due to either larger N uptake or greater partitioning of the uptake N into grain, or both. At plant maturity, NHI reflects this preferential allocation of N into grain. Using Eqs. (3) and (4) as well as treatment means (Table 2), we separated the relative contributions of both NHI and N uptake to N utilization in corn. On the basis of this relationship, N uptake accounts for 72% and NHI explains 28% of the difference in N utilization between the highest and lowest N utilization across treatments. This analysis suggests that N uptake is a greater contributor than NHI to increasing N utilizations when comparing diverse N management strategies. Differential soil N availability across treatments might have led to this greater impact of N uptake on N utilization in our study. Previous research has shown NHI parameter to be more related to plant species and genotype than to management and/or other environmental factors (Kumudini et al., 2001; Worku et al., 2007). Other plant physiological mechanisms may also drive N utilization results. Source:sink ratio data by Tollenaar and Daynard (1982) and Rajcan and Tollenaar (1999) in corn and by Dordas (2009) in wheat can suggest varying N sink size during grain filling stages as a partial explanation for preferential N translocation into grain. Future studies can investigate temporal dynamics of interacting N utilization components (N uptake and NHI) along with plant N remobilization as grain filling occurs in corn fields.

4.2. N source effects on corn N partitioning and yield

Compared to manure treatments, UAN additions resulted in enhanced N uptake and utilization which appeared to translate in superior corn yield performance (Tables 1 and 2). As also suggested by Dauden and Quilez (2004), compared to soils receiving mineral N additions, most of N in manured soils could have been both mostly immobilized and subject to a high demand by soil microbial competition (Hernandez-Ramirez et al., 2009a). Therefore, corn plants may have hypothetically acquired sufficient N for initial vegetative growth; however, reproductive growth could have been restricted later in the growing season due to low soil N availability. These inferences are consistent with Worku et al. (2007) who found increasing N uptake and N utilization after flowering as key contributors to enhanced yield performance across tropical maize hybrids, particularly under soil N limiting conditions.

Irrespective of the N source, NHI trended to increase with both grain N content and DM grain accumulation (Fig. 2). Overall, these observed patterns may suggest both the pronounced association between varying grain N contents and N partitioning as well as the substantial contributing-role of NHI to yield gain. Also, it is noteworthy that manured fields resulted in more variable NHI values than fields receiving UAN (Fig. 2). This greater consistency in N partitioning where UAN was applied can indicate an enhanced yield prediction ability for production systems under this N management compared to use of manure as N source.

Although DMHI values were near constant across treatments, manured fields (CCSM and CCFM) slightly trended to diminish DMHI compared to fields receiving UAN (Table 2). Nonetheless, these observed narrow differences in DMHI (e.g., 0.52 vs. 0.55) may have a limited biological significance. However, these DMHI patterns in our study captured tendencies similar to reports by Kwaw-Mensah and Al-Kaisi (2006) who concluded that commercial N fertilizers generally produced a much greater DMHI (0.60) than fall liquid swine manure (0.50) in corn fields fertilized at various N rates ranging from 85 to 250 kg N ha^{-1} yr^{-1}. Conversely, other studies have found no differences in DMHI across varying N fertilization management. Loecke et al. (2004) did not detect differences in DMHI (overall mean = 0.47) for corn as a response to fresh vs. composted swine manure, perhaps because of their high rate of N application compared to our experiment (i.e., Loecke's rate: 340 vs. our study: 255 kg N ha^{-1} yr^{-1}). Likewise, data by Berenguer et al. (2008) indicate no differences in DMHI (overall mean = 0.50) for corn when using swine slurry and/or ammonium nitrate as N source.

4.3. Effects of manure timing on corn N partitioning and yield

Although yield response to manure timing was variable across individual experimental years (Tables 1 and 2), corn productivity based on the 2-yr means (measured as both grain harvested by hand and yield by combine; Table 2) was superior with spring vs. fall manure additions during the later years of the experiment. As for yield, manure timing was expected to cause a parallel effect on N partitioning. However, based on the 2-yr means, N utilization by corn appeared to be unaffected by manure timing (Table 2). Nonetheless, detailed examination of this data by individual experimental year revealed opposite effects of spring vs. fall manure timing on N utilization across the years (i.e., CCFM > CCSM in 2005 and CCFM < CCSM in 2006; $Ps < 0.05$). These observed wide year-to-year fluctuations in N utilization could be primarily caused by variations in both manure characteristics and weather conditions across the experimental years. Such inter-annual variations in corn N partitioning parameters as a function of spring vs. fall manure timing is not well documented in the existing literature. Furthermore, these general inferences are consistent with previous reports for corn cropping systems receiving repeated spring manure additions under a broad variety of ecophysical conditions. After a 4-yr experiment assessing combined fertilization with swine slurry and ammonium nitrate in irrigated corn, data by Berenguer et al. (2008) suggest, as in our study, ample inter-annual variations in partitioning parameters, N uptake, and productivity to take place in partial association with varying manure properties. Similarly, both Talarczyk et al. (1996) and Loecke et al. (2004) also reported high year-to-year inconsistencies in corn yield responses and DM partitioning when using spring manure applications. Similar to our study, they attributed these results to variable cool-wet soil conditions during certain early growing seasons thus limiting N transformation and availability, and hence plant uptake.

Acknowledgments

We thank L. Wright, J. Turner, M. Thom, B. Hofmann, and R. Graef for their technical assistance and B. Joern for coordinating the manure applications. We acknowledge financial support by USDA-NRI (Soil and Soil Biology Program), USDA-CSREES (Cooperative State Research Service), and CSREES-NRI (Watershed Processes and Water Resources).

References

Berenguer, P., Santiveri, F., Boixadera, J., Lloveras, J., 2008. Fertilisation of irrigated maize with pig slurry combined with mineral nitrogen. Eur. J. Agron. 28, 635–645.

Dauden, A., Quilez, D., 2004. Pig slurry versus mineral fertilization on corn yield and nitrate leaching in a Mediterranean irrigated environment. Eur. J. Agron. 21, 7–19.

Dordas, C., 2009. Dry matter, nitrogen and phosphorus accumulation, partitioning and remobilization as affected by N and P fertilization and source–sink relations. Eur. J. Agron. 30, 129–139.

Hernandez-Ramirez, G., Brouder, S.M., Smith, D.R., Van Scoyoc, G.E., 2009a. Carbon and nitrogen dynamics in an eastern Corn Belt soil: nitrogen source and rotation. Soil Sci. Soc. Am. J. 73, 128–137.

Hernandez-Ramirez, G., Brouder, S.M., Smith, D.R., Van Scoyoc, G.E., 2009b. Greenhouse gas fluxes in an eastern Corn Belt soil: Weather, nitrogen source and rotation. J. Environ. Qual. 38, 841–854.

Kumudini, S., Hume, D.J., Chu, G., 2001. Genetic improvement in short season soybeans: I. Dry matter accumulation, partitioning, and leaf area duration. Crop Sci. 41, 391–398.

Kwaw-Mensah, D., Al-Kaisi, M., 2006. Tillage and nitrogen source and rate effects on corn response in corn–soybean rotation. Agron. J. 98, 507–513.
Liu, W.D., Tollenaar, M., Stewart, G., Deen, W., 2004. Response of corn grain yield to spatial and temporal variability in emergence. Crop Sci. 44, 847–854.
Loecke, T.D., Liebman, M., Cambardella, C.A., Richard, T.L., 2004. Corn response to composting and time of application of solid swine manure. Agron. J. 96, 214–223.
Rajcan, I., Tollenaar, M., 1999. Source:sink ratio and leaf senescence in maize: I. Dry matter accumulation and partitioning during grain filling. Field Crops Res. 60, 245–253.
SAS Institute, 2002. SAS, version 9.1. SAS Institute, Cary, NC.
Talarczyk, K.A., Kelling, K.A., Wood, T.M., Hero, D.E., 1996. Timing of manure application to cropland to maximize nutrient value. In: Proc. 1996 Wisconsin Fert., Aglime, and Pest Manage. Conf. ,. Univ. of Wisconsin, Madison, Madison, WI, pp. 257–263.
Tollenaar, M., Daynard, T.B., 1982. Effect of source:sink ratio on dry matter accumulation and leaf senescence of maize. Can. J. Plant. Sci. 62, 855–860.
Worku, M., Bänziger, M., Schulte aufm Erley, G., Friesen, D., Diallo, A.O., Horst, W.J., 2007. Nitrogen uptake and utilization in contrasting nitrogen efficient tropical maize hybrids. Crop Sci. 47, 519–528.